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To: Mr. D.E. Horrocks
Manager, Transmission Lines Programs
Design and Development - Transmission

Attn: Mr. V.G. Novotny

SHAFTSBURY JCT TO BAYVIEW JCT THERMAL RESISTIVITY SURVEY FOR EXISTING 115 kV LPOF CABLES

H.S. Radhakrishna

Thermal resistivity measurements were made at 6 locations along the existing 115 kV LPOF cables between Shaftsbury Jct to Bayview Jct. The field and laboratory analysis confirmed the potential hotspot conditions over a 150 m stretch along Shaftsbury Avenue.

INTRODUCTION

At the request of Mr. V.G. Novotny, Transmission Lines Programs Department, a soil thermal resistivity survey was carried out for the existing 115 kV LPOF U/G cables (Circuit L14W) between Shaftsbury Jct and Bayview Jct during April 4 to 7, 1989. This study was undertaken to establish the cable loading limitation and possible need for replacing this 35 year old system.

At present there is a proposal to install a 115 kV HPOF pipe type cable system from Shaftsbury Jct to Bridgeman TS and from Bridgeman TS to Balfour Jct. A thermal survey will be carried out shortly for this proposed cable route and the results will be reported separately.

IN SITU MEASUREMENTS

Six test pits were excavated at locations as shown in Figure 1. These locations were selected on the basis of the results of an earlier thermal resistivity survey done along this cable route in 1961/1/ and the ease of accessibility to the test locations. The thermal resistivity survey carried out in 1961 for this operating circuit had shown a high thermal resistivity of 140^{o}C.cm/W over a 150 m long section of the cable route along Shaftsbury Avenue about 210 m from Shaftsbury Jct/1/. These measurements were performed by inserting a 1.8 m long thermal needle from the ground surface into the soil adjacent to the cable route. The report summarizing the test results and design recommendations, is appended with this report.

job	file	date	report no.
43-124-432	843.11	June 19, 1989	89-143-K

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The test pits showed that the LPOF cables were buried at an average depth of 1.5 m below the ground surface in a 20 to 30 cm thick layer of sand (referred to as thermal sand in this report). On top of the thermal sand, 10 cm thick protective concrete slabs were present, above which was the native soil backfill extending to the ground surface. Figure 2 shows a typical cross section of cable trench.

The test pits were excavated with a backhoe down to the protective concrete slabs over the cables and then a small test pit was hand dug by the side of the concrete slab exposing the thermal sand around the cables (Figures 3 to 8). The field thermal probes (0.3 m long and 6 mm in diameter) were inserted horizontally into the thermal sand between the cables and the concrete slab. Two measurements in the thermal sand and 4 measurements in the backfill above the concrete slabs were taken in each test pit (Figure 3).

Samples of thermal sand and backfill material above the concrete slabs were taken either by driving a steel tube into the soil or by scooping out the soil into a plastic container.

The thermal sand was of a silty sand type in Test Pit 1 while in Test Pits 2 to 6 it was fine sand with small amounts of silt. The fill material above the concrete slabs varied from silty sand with gravel and some organics to clayey sand. An extensive root system was observed in Test Pits 1, 2, 5 and 6 where trees were present adjacent to the cable route (Figures 3, 6 and 7). Medium sized maple trees were present all along Shaftsbury Avenue and Carstowe Avenue (Figures 2, 6 and 7).

Moist to dry soil conditions were present in Test Pits 1, 2 and 4 with no free water. In Test Pits 3, 5 and 6, the soils were generally saturated and there was seepage of groundwater at the floor of the test pits (Figures 4 and 6). Since this survey was performed in the spring season, the soil moisture was at its seasonal high.

The measured in situ thermal resistivity values of the thermal sand was in the range of 50 to 60^{o}C cm/W where the soil moisture was high (Test Pits 3 to 6) and it was in the range of 200 to 350^{o}C cm/W in Test Pits 1 and 2 where the soils were moist to dry and the tree root system had penetrated the sand. The measured in situ thermal resistivity values of the native soil backfills above the concrete slabs ranged from 60 to 90^{o}C cm/W.

LABORATORY ANALYSIS

Representative and undisturbed tube samples were taken from the thermal sand around the cables and the fill materials above the concrete slabs. At locations where the thermal sand did not extend far enough outside the concrete slabs, the sand adjacent to the outside cable was scooped out and collected in sealed jars. In the fill material above the concrete slabs, a thick walled 45 mm ID steel tube was driven horizontally into the soil and an undisturbed sample was recovered for laboratory testing.

The laboratory tests on soil samples included:

1. moisture content and density determination
2. grain size analysis
3. thermal resistivity vs moisture content determination

Table I summarizes the results of field and laboratory test data. Table II shows the percentage of sand, silt and gravel content in the fill materials above the concrete slabs.

The thermal resistivity vs moisture content curves were obtained by drying a 120 mm long segment of the tube sample in stages or by reconstituting the test sample at different moisture levels but to a constant density. The latter procedure generally gives slightly higher thermal resistivity values at lower moisture contents than those obtained by a stage drying technique. In the case of the thermal sand, since there were only a few tube samples recovered, the test specimens had to be reconstituted at different moisture levels.

Figures 9 to 12 show the thermal resistivity vs moisture content data from the laboratory tests from which the following observations can be made:

1. The thermal resistivity of the thermal sand is strongly dependent on the moisture content below the critical moisture level of 4 to 5% by dry weight.

2. The high thermal resistivity values of the thermal sand measured in Test Pit 2 could not be reproduced in the laboratory by reconstituting the sand sample at its moisture content of 5% by dry weight (Figure 9).

3. In Test Pit No 2, the moisture content of the sand in between the cables was likely to be drier than outside the cables where the samples were collected for laboratory testing. From the thermal resistivity vs moisture content curve for thermal sand (Figure 9), a zero per cent moisture will give the thermal resistivity comparable to in situ values of 400^{o}C cm/W.

4. A combination of near dry moisture and loose density conditions caused by the extensive tree root system in the thermal sand at Test Pit 2 could be the reason for the very high value of in situ thermal resistivity.

5. Thermal resistivity vs moisture content curves for backfill materials above the concrete slabs also showed the critical moisture levels in the range of 4 to 6 per cent and total dry thermal resistivities in the range of 300 to 370^{o}C cm/W.

DISCUSSION AND RECOMMENDATIONS

Considering that the in situ measurements were performed in April when the soil moisture levels were at their seasonal high, the worst condition thermal resistivities were estimated on the basis of the expected lowest moisture

levels by carrying out Thornthwaite soil moisture budget estimates using the soil weather analysis program. The following are the predicted worst case thermal resistivity values:

Soil Type	Worst Case m/c %	Worst Case Thermal Resistivity ^{o}C.cm/W	Return Period (years)
thermal sand	1.0	350	50
backfill above concrete slab at Test Pits 1 and 2	4.0	140	50

CONCLUSIONS

The thermal resistivity measurements made by six test pits along the cable route confirmed the presence of a hotspot over a stretch of 150 m along Shaftsbury Avenue at about 200 m east of Shaftsbury Jct. The measured in situ thermal resistivity of the thermal sand in this hotspot area was in the range of 300 to 400^{o}C.cm/W while the thermal resistivity of the native soil backfill ranged from 60 to 90^{o}C cm/W. Over the remaining portion of the cable route, the soils were nearly saturated and gave low thermal resistivity values. With the presence of mature trees all along the cable route in Shaftsbury Avenue and Carstowe Avenue, the soil moistures are likely to deplete down to and below the critical moisture levels. Based on a soil moisture analysis, the worst case thermal resistivity values for the hotspot section are recommended to be 350^{o}C cm/W for the thermal sand and 140^{o}C cm/W for the natural soil backfill above the concrete slabs.

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Reviewed by:

T.J. Carmichael
Supervising Engineer
Soil Sciences Section

HSR:LM

TABLE I

Summary of In Situ and Laboratory Thermal Resistivity Test Results

Test Pit No	Sample Location	Moisture Content %	Dry Density kg/m^3	Organic Content %	In Situ TR $^oC.cm/W$	Lab TR $^oC.cm/W$
TP-1	Thermal sand	9.0	1480	6.0	190	120
	0.3 m above concrete slab	15.0	1520		80	68
	0.8 m above concrete slab	13.5	1730		65	58
TP-2	Thermal sand	5.0	1450	13.0	300-400	250
	0.4 m above concrete slab	18.0	1510	26.0	80	72
	0.8 m above concrete slab	16.0	1610	32.0	93	60
TP-3	Thermal sand	17.3	1540		87	76
	0.15 m above concrete slab	14.9	1570		65	62
	0.4 m above concrete slab	15.0	1540		63	59
TP-4	Thermal sand	12.0	1580		113	105
	0.45 m above concrete slab	7.5	1810		82	67
	0.8 m above concrete slab	9.8	1730		70	56
TP-5	Thermal sand	27.0	1605		75	78
	0.2 m above concrete slab	20.5	1690	20.0	66	70
	0.4 m above concrete slab	20.3	1590		65	69

TABLE II

Grain Size Analysis Data

Test Pit No	Sample Location	Silt %	Fine Sand %	Medium Sand %	Coarse Sand %	Fine Gravel %
TP-1	Thermal sand	37	63	0	0	0
TP-2	Thermal sand	15	72	3	2	8
TP-4	Thermal sand	12	83	3	1	1
TP-6	Thermal sand	7	77	16	0	0
TP-2	0.72 m above concrete slab	53	34	7	1	5
TP-4	0.45 m above concrete slab	20	61	10	2	7
TP-6	0.8 m above concrete slab	40	50	4		6

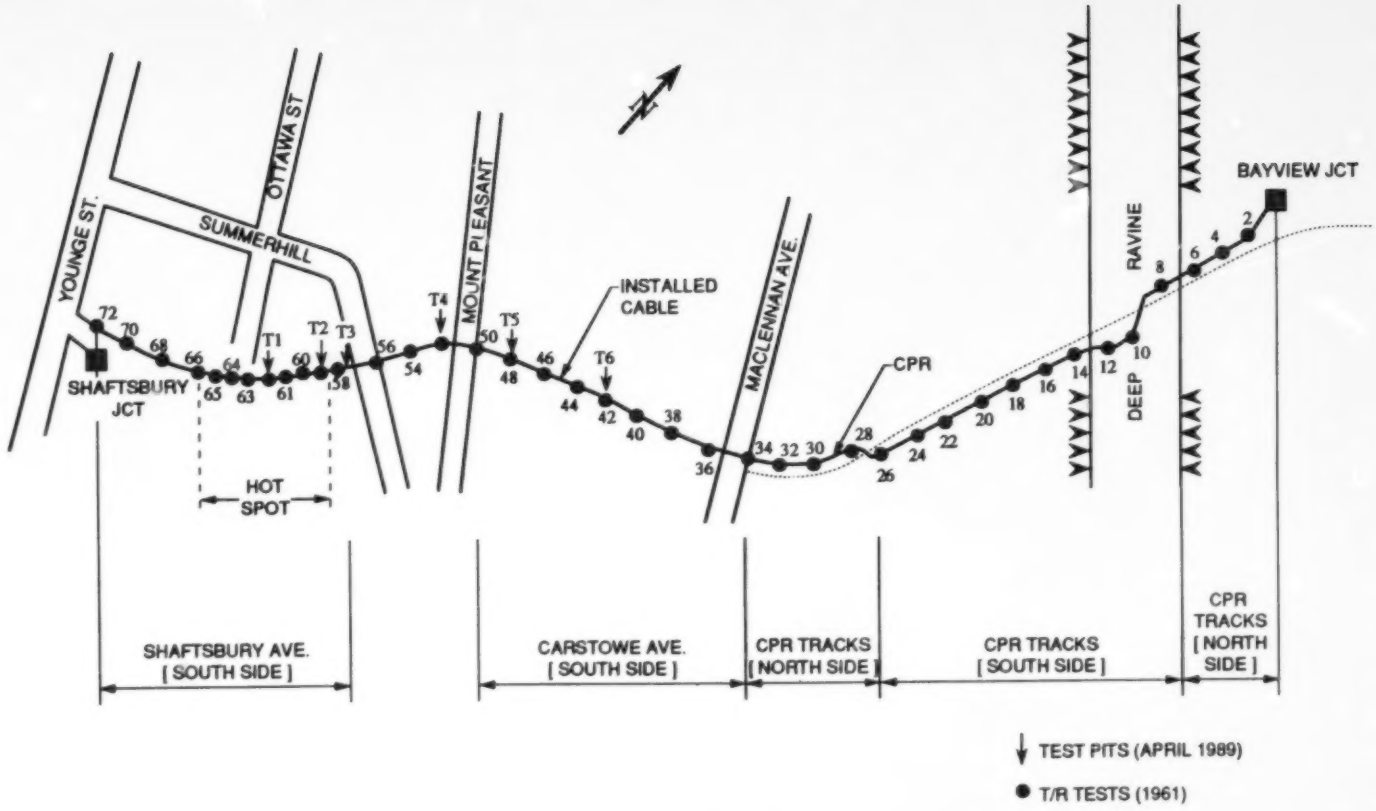


FIGURE 1

APPROXIMATE LOCATION OF 115 KV UNDERGROUND CABLE ROUTE
SHAFTSBURY JCT - BAYVIEW JCT

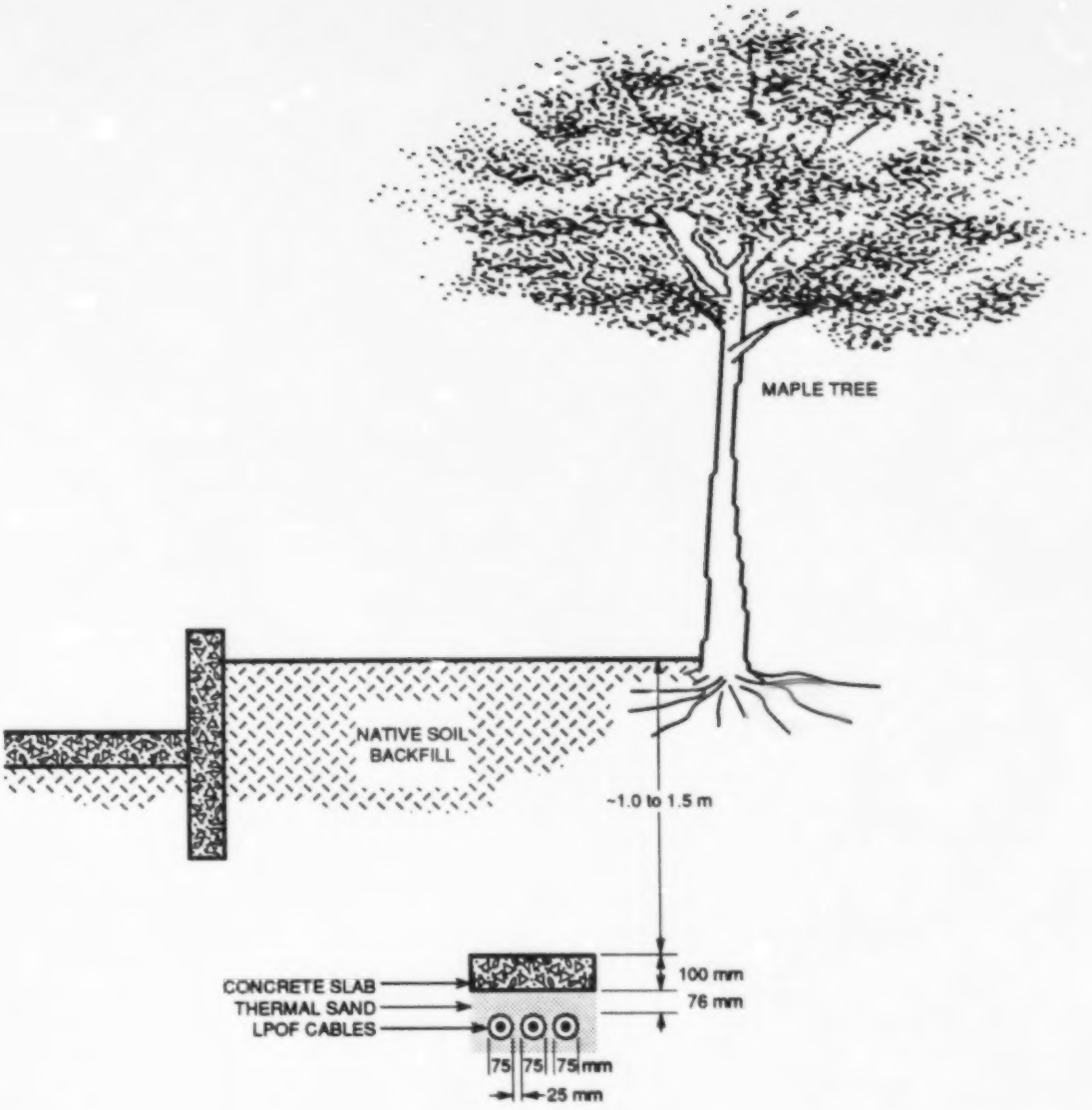
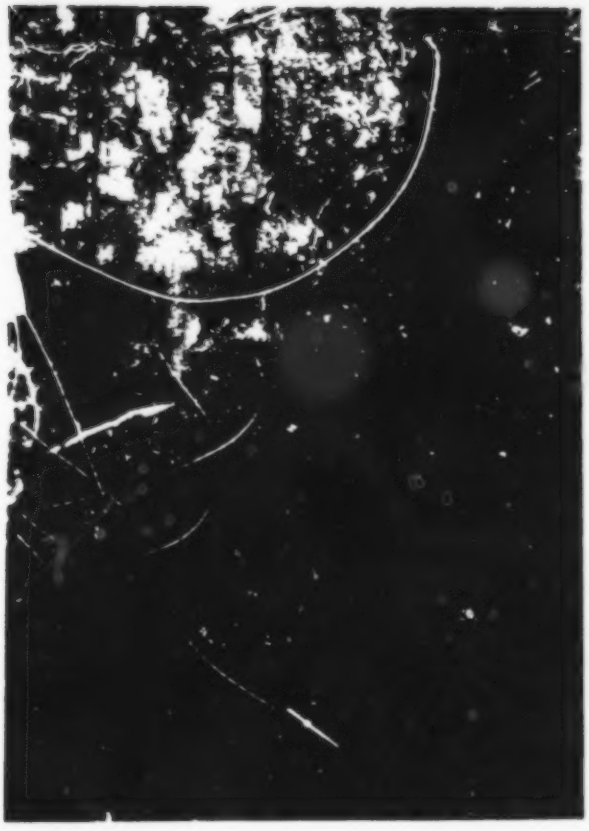


FIGURE 2

TYPICAL CROSS - SECTION OF CABLE TRENCH
SHAFTSBURY JCT TO BAYVIEW JCT EXISTING 115 KV LPOF CABLES

Excavation of
test pits to the
top of concrete slabs



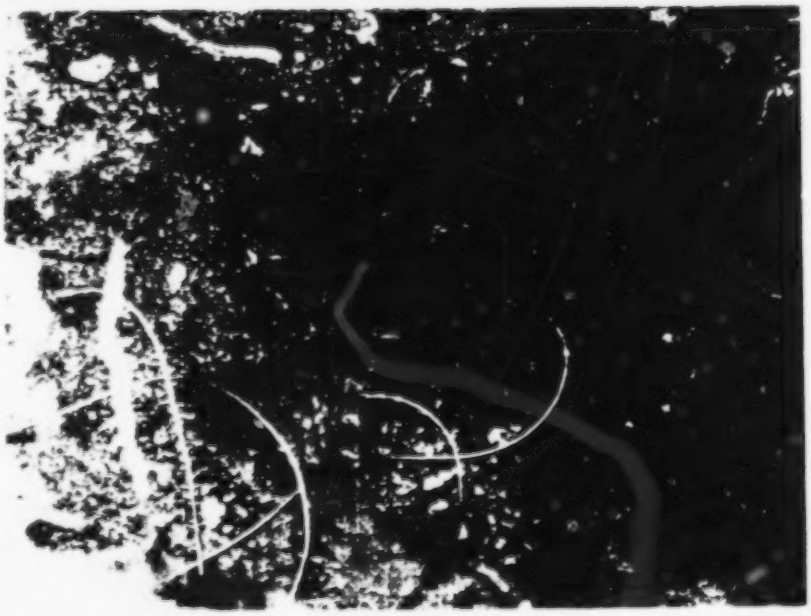
Thermal probes installed
in the walls of the test pit

FIGURE 3

THERMAL RESISTIVITY SURVEY SHAFTSBURY
JCT TO BAYVIEW JCT EXISTING 115 kV LPOF CABLES

190008-G16-RD

Maple trees along side the cable route



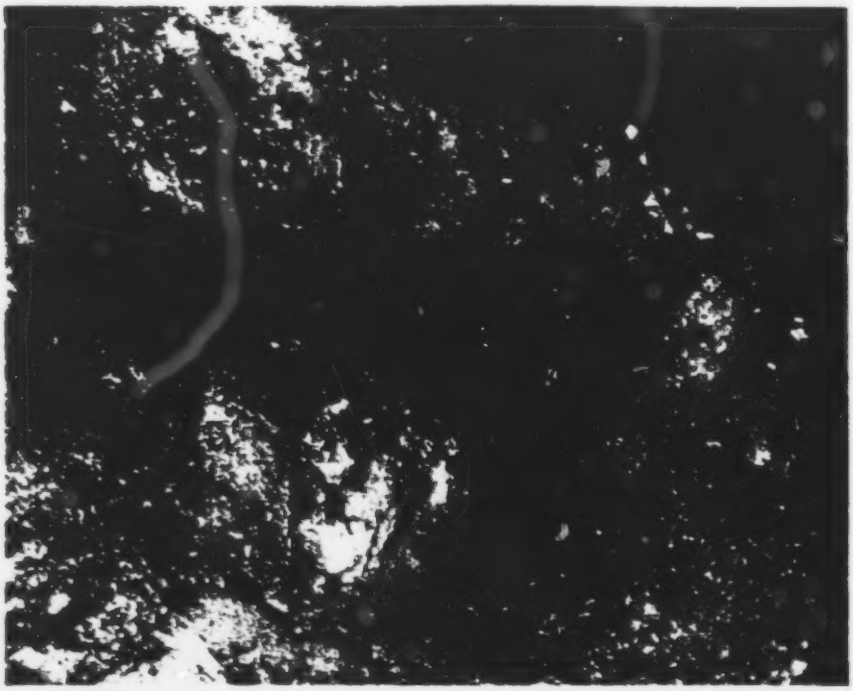
Extensive root system in backfill above and below concrete slabs

Low moisture condition in thermal sand

FIGURE 4

SOIL CONDITIONS IN TEST PIT 2
SHAFTSBURY AVENUE

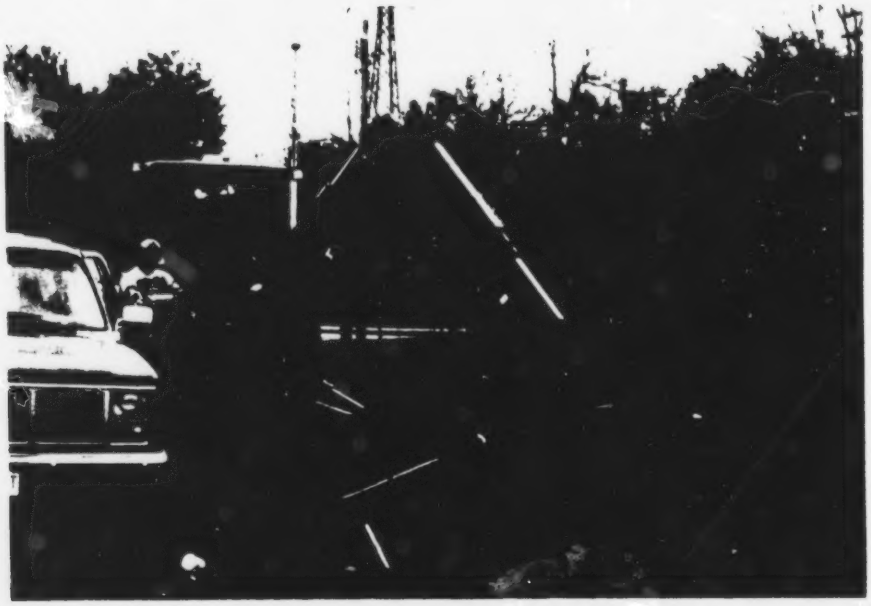
180009-G16-RD



Sandy soils in
moist condition

FIGURE 5

SOIL CONDITIONS IN TEST PIT 3
SHAFTSBURY AVENUE AT SUMMERHILL AVENUE

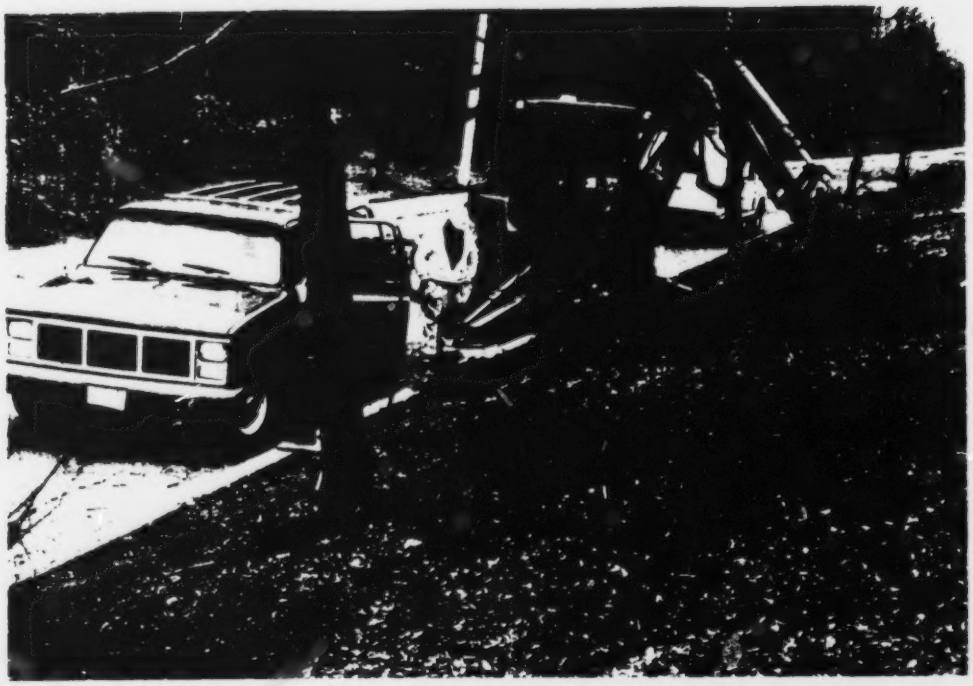


Sandy soils in
moist condition

FIGURE 6

SOIL CONDITIONS IN TEST PIT 4
WEST OF MOUNT PLEASANT ROAD

180011-G16-RD



Maple trees along the cable route

Ground water seepage

FIGURE 7

SOIL CONDITIONS IN TEST PIT 5
CARSTOVE AVENUE EAST OF MOUNT PLEASANT ROAD

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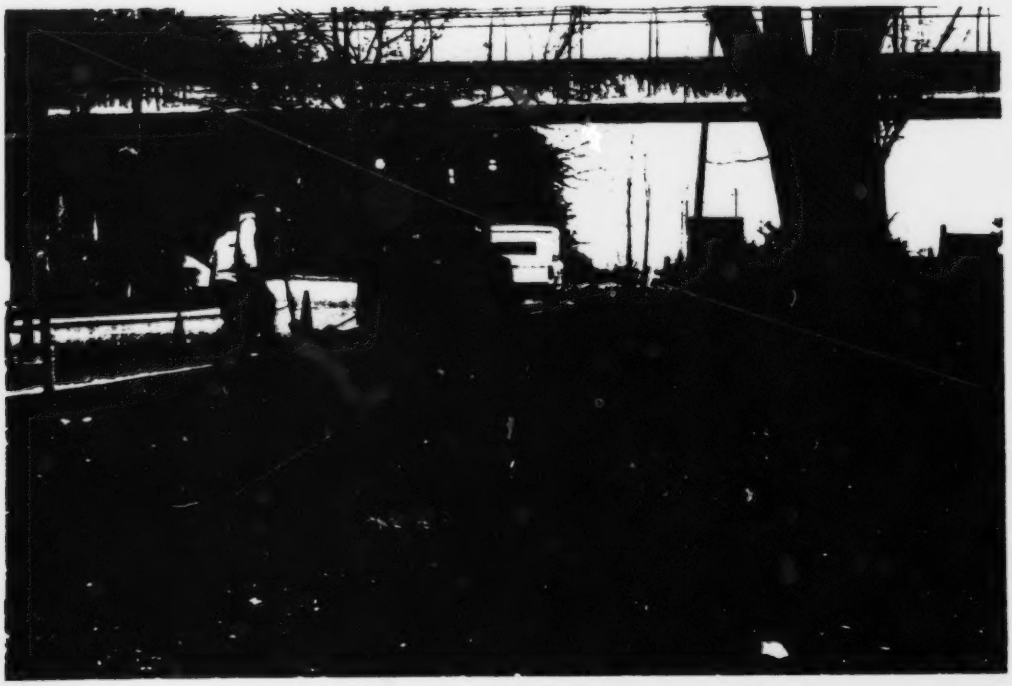

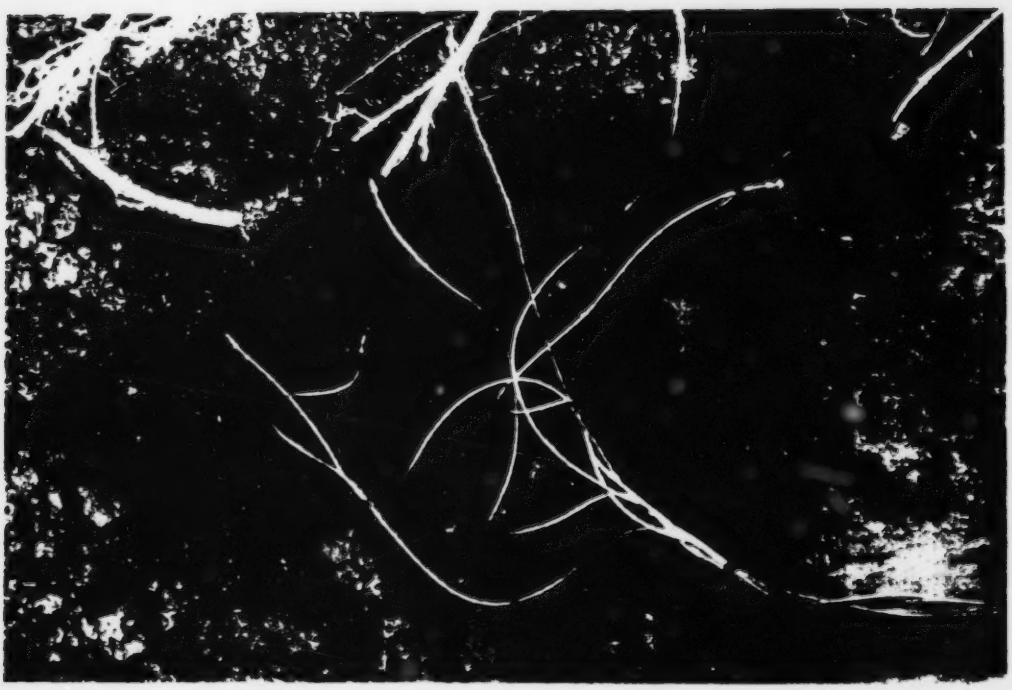

FIGURE 8

SOIL CONDITIONS IN THE TEST PIT 6
CARSTOVE AVENUE BESIDES LARGE TREE

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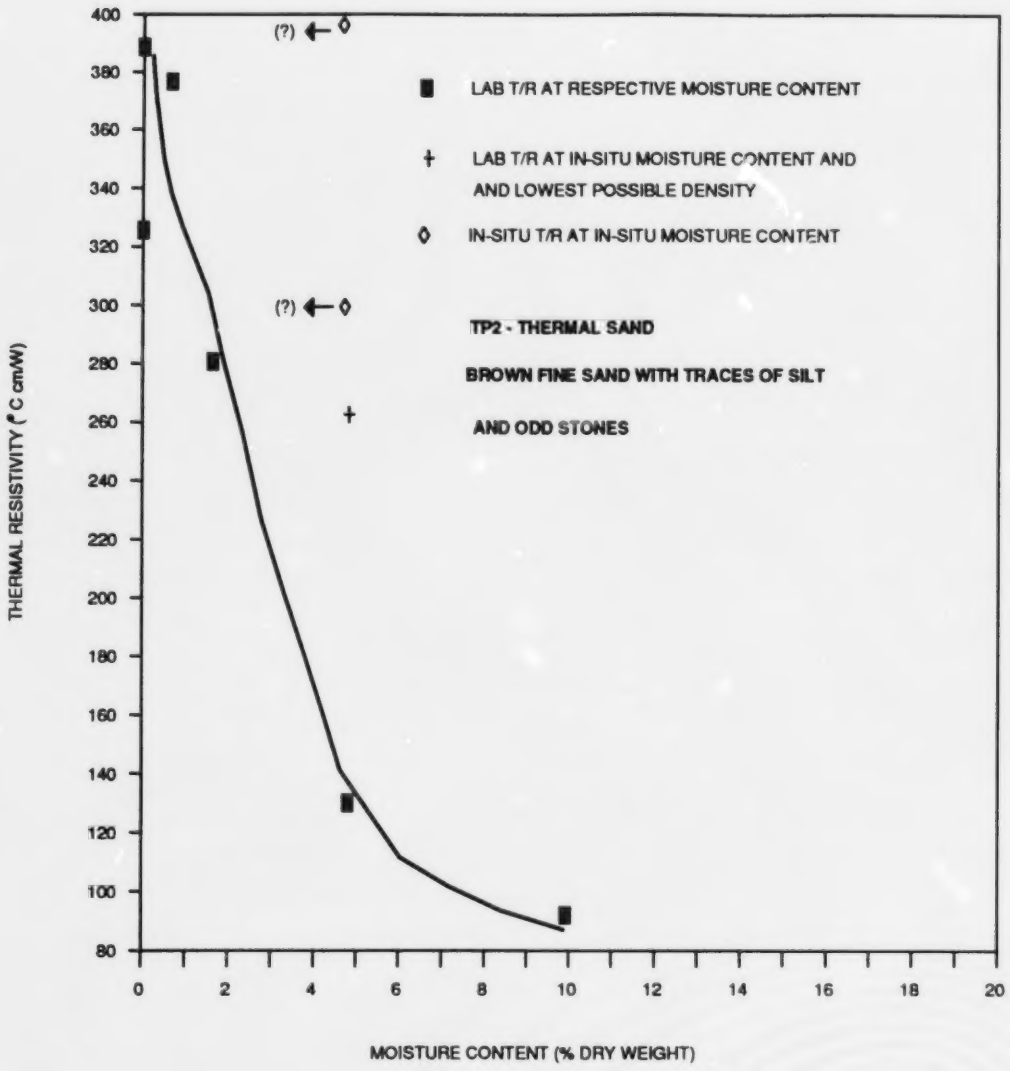

FIGURE 9

THERMAL RESISTIVITY vs MOISTURE CONTENT

CURVE FOR THERMAL SAND

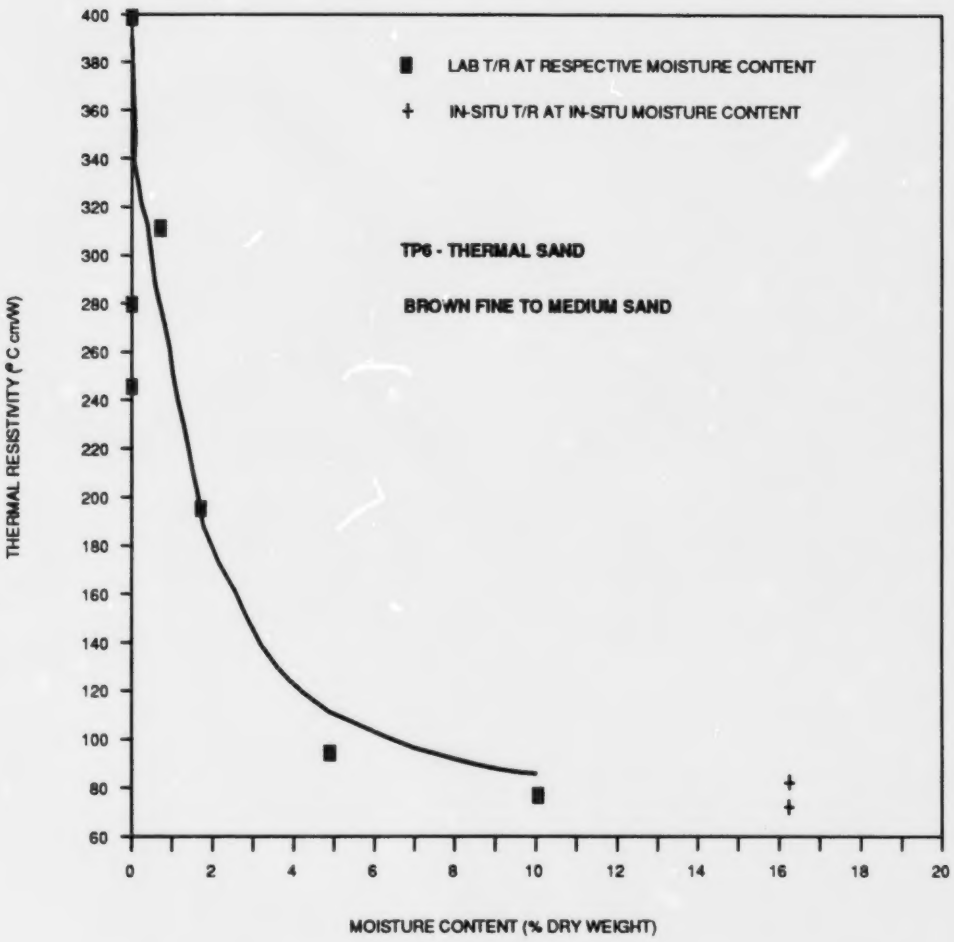

FIGURE 10

THERMAL RESISTIVITY vs MOISTURE CONTENT CURVE FOR THERMAL SAND

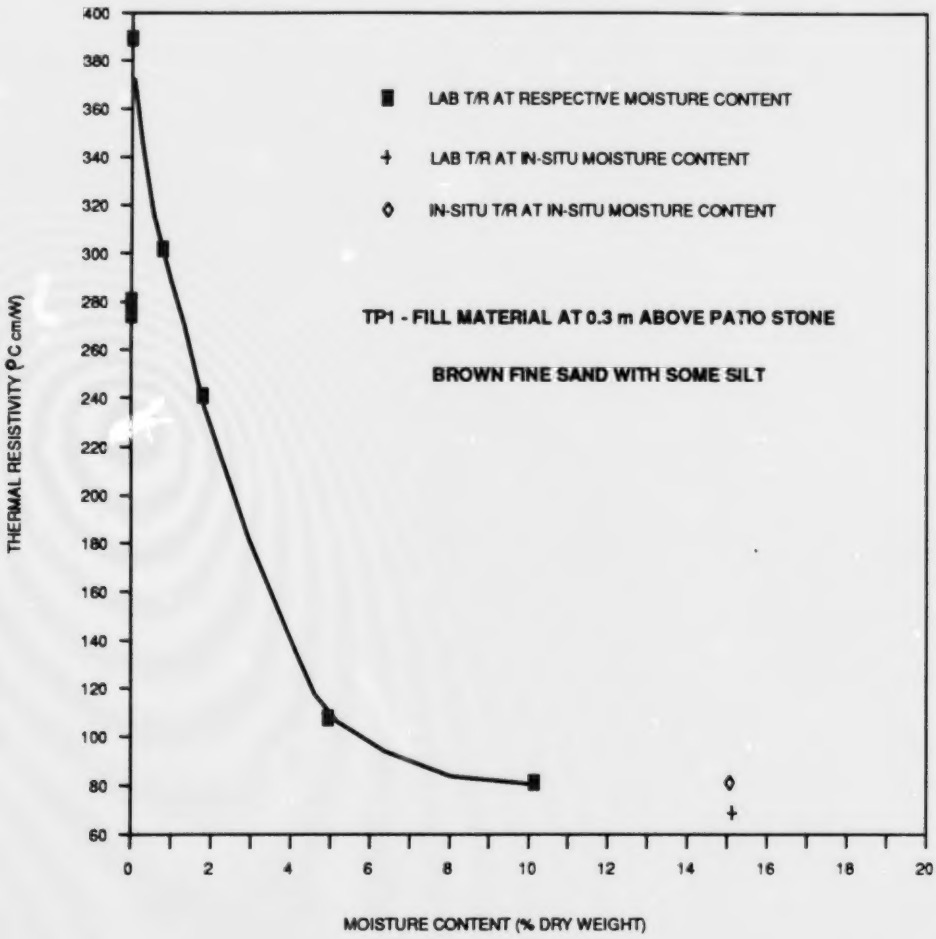

FIGURE 11

THERMAL RESISTIVITY vs MOISTURE CONTENT

CURVE FOR FILL MATERIAL

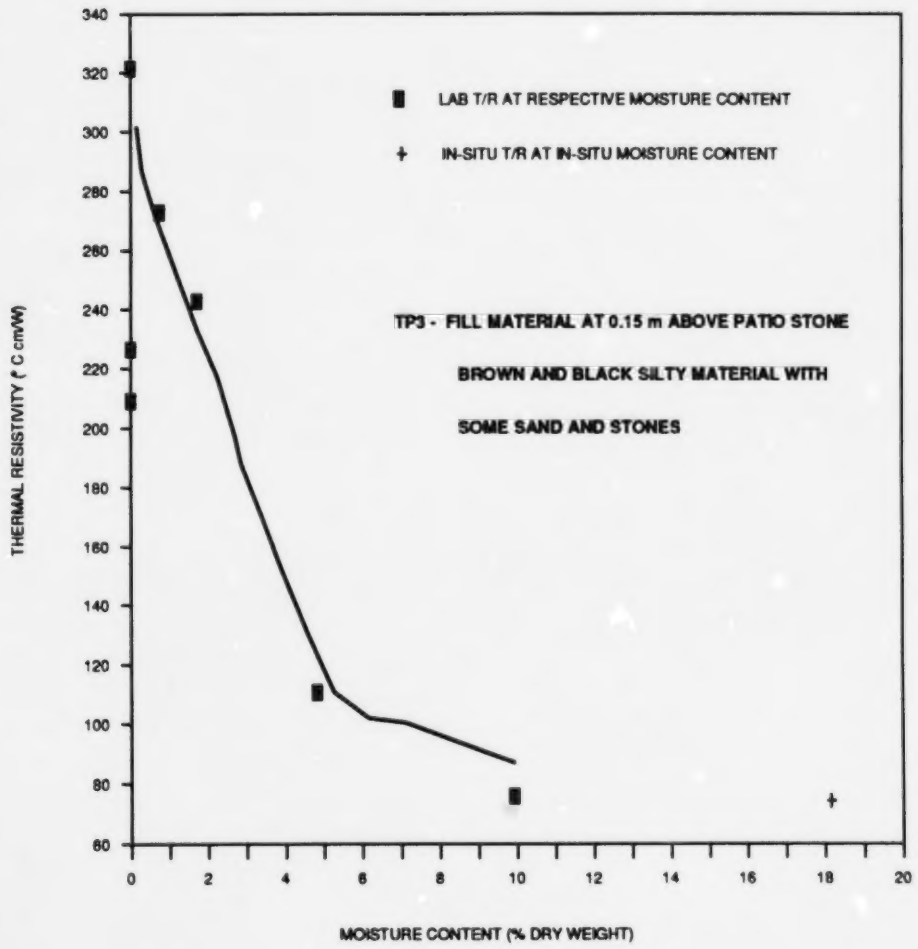

FIGURE 12

THERMAL RESISTIVITY vs MOISTURE CONTENT CURVE FOR FILL MATERIAL

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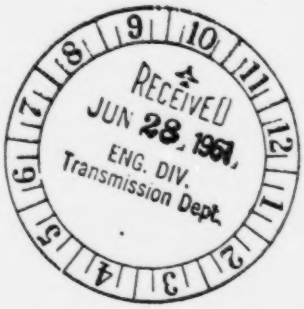
APPENDIX

THE HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
RESEARCH DIVISION REPORT



To Mr. W.J.F. Baxter,
Transmission Engineer.

Attention: Mr. A.H. Anderson

THERMAL RESISTIVITY INVESTIGATION ALONG EXISTING 115-KV UNDERGROUND CABLE ROUTE BAYVIEW JCT. - SHAFTESBURY JCT.

Thermal resistivity measurements were made along the underground cable route between Bayview Jct. and Shaftesbury Jct. Results of this investigation indicate a design value of 140C cm/watt.

At the request of Mr. R. Murray, Transmission Department measurements of soil thermal resistivity (t/r) were made along the underground cable route between Bayview Jct. and Shaftesbury Jct. Central Region. The original t/r investigation was carried out over several months during the year 1954 (Research Division Report No. 54-453). The many advances in the field of t/r measurements makes the original survey inconclusive, also results of other t/r investigations have shown seasonal variations in t/r as high as 3 to 1 on a particular cable route. The present t/r investigation was carried out during a period of low moisture input, considered the most probable period in which to measure the highest t/r values.

TESTS

Thermal resistivity and moisture content measurements of the soil adjacent to the cable route were made at intervals of approximately 200 feet along its entire length and at 100-foot intervals along sections of high t/r.

Thermal resistivity measurements were made by means of a transient needle MK III which determines the t/r of soil at depths of 3.5 and 4.5 feet below grade.

The determination of moisture content of the soil in the field was facilitated by the use of a commercially available moisture meter.

JOB	FILE	DATE	REPORT No.
740646-14-1303	813.41	June 20, 1961	61-197

RESULTS

Table I at the end of this report gives all the data collected during the investigation.

Figure I indicates the cable route. Figure II graphically represents test results listed in Table I.

Measurements were made as close to the cables as possible (approximately 9 to 12 inches). The test locations close to the energized cables were located by means of an electromagnetic pickup.

CONCLUSIONS

A 500-foot section of cable route approximately 700 feet away from Shaftesbury Jct. has an average t/r value of 140C cm/watt. This high t/r value is caused by the unusually low soil moisture content. Results of tests conducted in good thermal sand indicate a similar value of t/r at a moisture content of 5 per cent. Therefore, a redesign value of 140C cm/watt must be considered for the entire cable route unless artificial cooling is carried out on the 140C cm/watt section of cable route shown by this investigation.

The original proposed design value of 80C cm/watt may be used for the remaining sections of cable route.

Approved:

J.H. Waghorne,
Engineer-in-Charge,
Electrical Research Department.

Submitted by,

J.W. Newall,
Supervising Technician,
Electrical Testing Section,
Electrical Research Department.

JWN:JLH

TABLE I

TEST LOCATION [FEET X 100]	THERMAL RESISTIVITY ^{0}C CM/WATT			MOISTURE CONTENT [% WET WEIGHT]	
	4.5 FEET	3.5 FEET	AVERAGE		
BAYVIEW JCT	57	79	68	8.7	
2	85	88	87	8.6	
4	80	84	82	9.2	
8	57	53	55	11.1	
12	44	45	45	10.1	
14	73	60	67	11.6	
16	49	43	46	14.0	
18	57	68	63	13.0	
20	84	91	88	11.5	
22	52	52	52	14.2	
24	38	54	46	9.2	
26	60	84	72	9.6	
28	85	100	93	8.6	
30	57	68	63	9.4	
32	58	72	65	16.8	
34	46	78	62	10.6	
36	79	49	64	11.6	
38	62	66	64	13.3	
40	58	44	51	19.0	
42	60	56	58	17.2	
44	86	86	71	16.2	
46	49	56	53	15.9	
48	32	55	44	16.8	
50	51	72	62	14.2	
52	55	63	59	9.8	
56	55	54	55	11.5	
58	87	84	86	11.2	
59	134	128	131	5.7	HOT SPOT
60	135	160	148	4.7	
61	134	128	131	4.0	
62	132	180	156	5.1	
63	140	120	130	5.2	
64	138	180	159	4.6	
65	69	73	71	9.1	
66	80	76	78	9.2	
68	91	97	94	7.8	
70	87	81	84	10.0	
SHAFTSBURY JCT.					

BAYVIEW JCT – SHAFTSBURY JCT
115–KV UNDERGROUND CABLE ROUTE

109947–RD

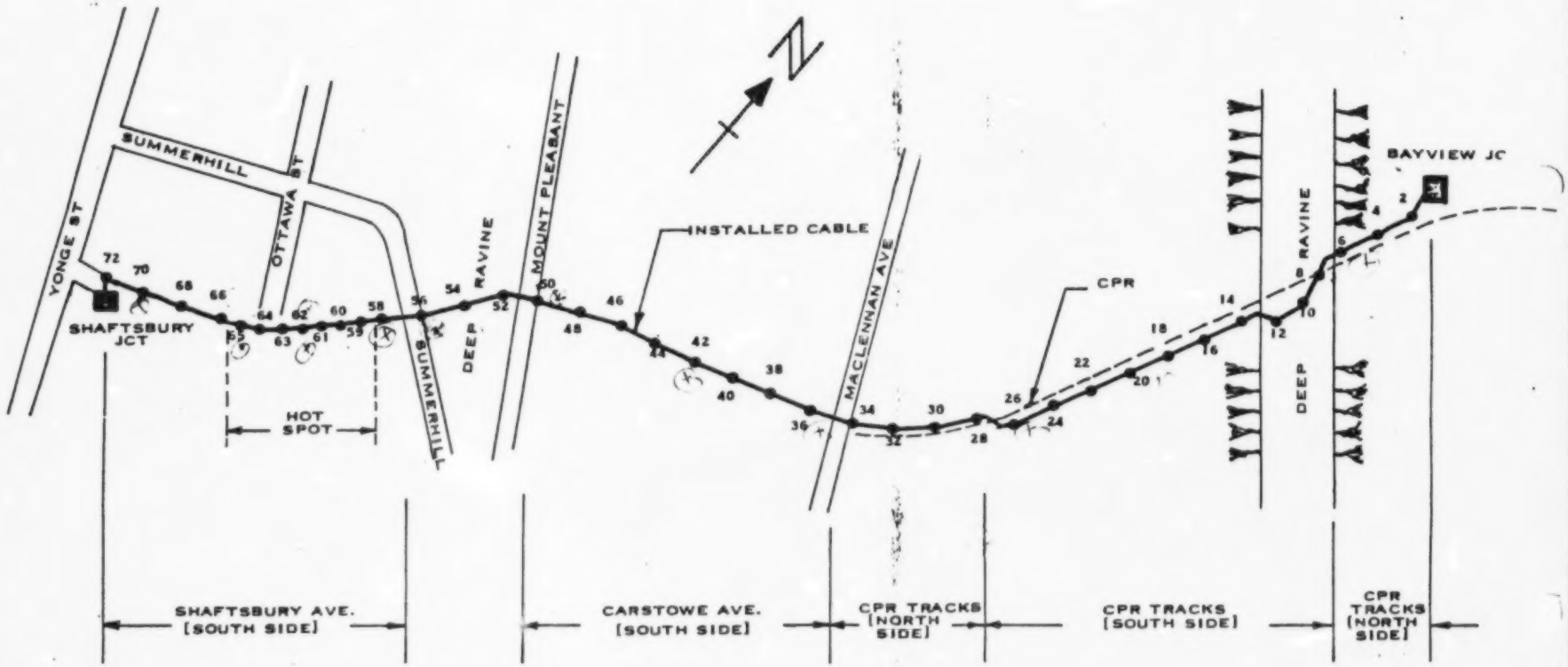


FIGURE 1

APPROXIMATE LOCATION OF 115 KV UNDERGROUND CABLE ROUTE
SHAFTSBURY JCT – BAYVIEW JCT

109943–RD

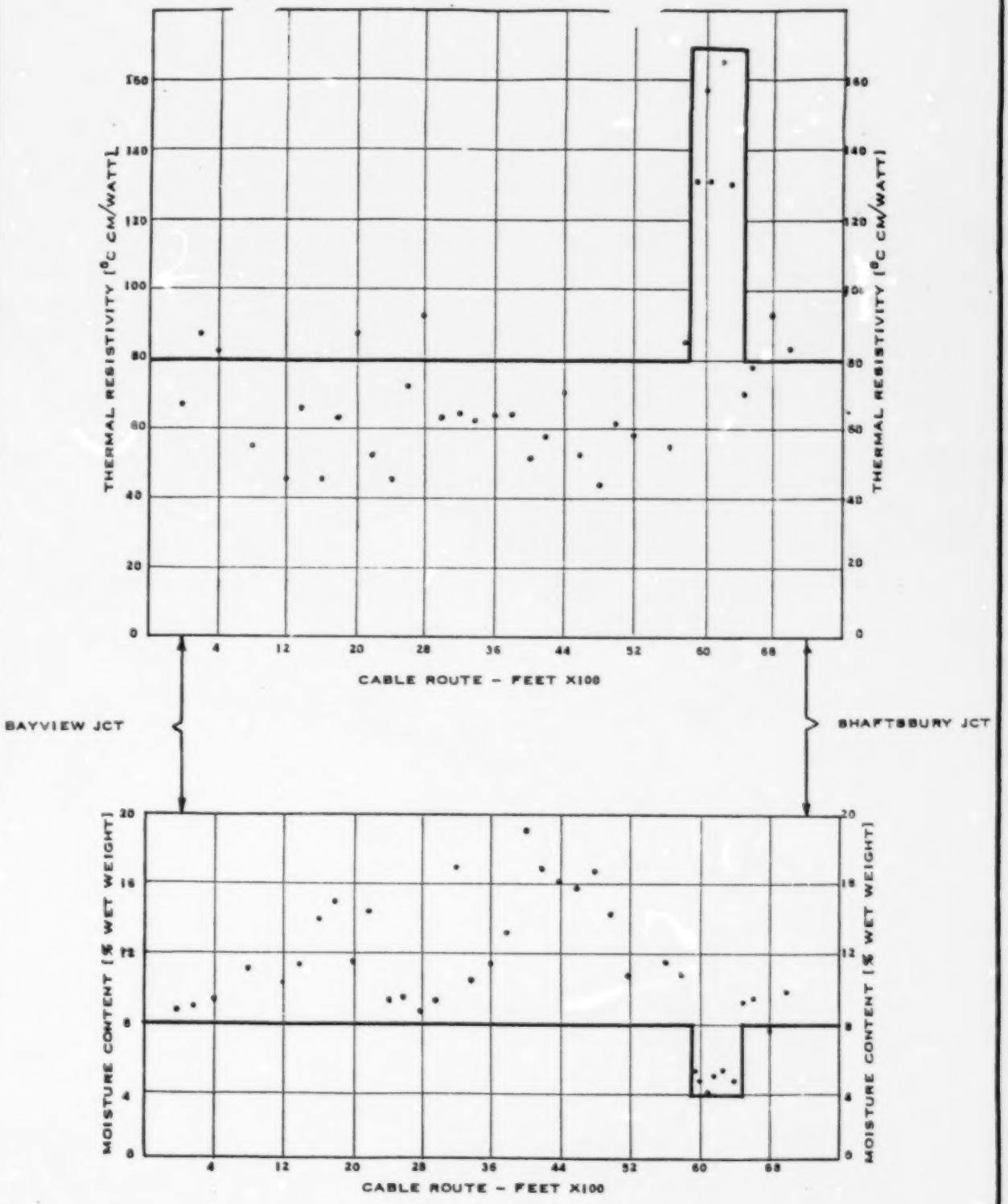


FIGURE 2

BAYVIEW JCT – SHAFTSBURY JCT
115–KV UNDERGROUND CABLE ROUTE

109944–RD